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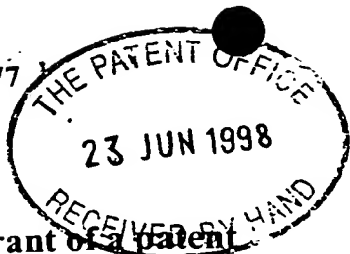
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HEPATITIS C RECEPTOR PROTEIN

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## Hepatitis C Receptor Protein

### Field of the Invention

- 5 The present invention relates to the use of CD81 protein and nucleic acid encoding this protein in the therapy and diagnosis of hepatitis C and to pharmaceutical compositions, animal models and diagnostic kits for such uses.

### Brief Description of the Prior Art

10

HCV (previously known as Non-A Non-B hepatitis - NANBV) is a positive sense RNA virus of about 10000 nucleotides with a single open reading frame encoding a polyprotein of about 3000 amino acids. Although the structure of the virus has been elucidated by recombinant DNA techniques (European patent application EP-A-  
15 0318216 and European patent application EP-A-0388232), the virus itself has not been isolated and the functions of the various viral proteins produced by proteolysis of the polyprotein have only been inferred by analogy with other similar viruses of similar genomic organisation (Choo *et al* PNAS USA (1991) 88 2451-2455).

20 The viral proteins are all available in recombinant form, expressed in a variety of cells and cell types, including yeast, bacteria, insect and mammalian cells (Chien, D.Y. *et al* PNAS USA (1992) 89 10011-10015 and Spaete, R.R. *et al* Virology (1992) 188 819-830).

25 Two proteins, named E1 and E2 (corresponding to amino acids 192-383 and 384-750 of the polyprotein respectively) have been suggested to be external proteins of the viral envelope which are responsible for the binding of virus to target cells.

HCV research is hindered very considerably by the limited host range of the virus. The  
30 only reliable animal model for HCV infection is the chimpanzee and HCV does not readily propagate in tissue culture.

In our copending International patent application PCT/IB95/00692 (WO 96/05513), we describe a method employing flow cytometry to identify cells carrying the HCV receptor. We have shown that, by labelling cells with recombinant E2 envelope protein, it is possible to sort cells using flow cytometry, isolating those cells capable of specific binding to the E2 and therefore potentially carrying the HCV receptor.

In our copending International patent application PCT/IB96/00943 (WO 97/09349), we have identified a protein capable of binding to the E2 envelope protein of HCV.

We have now succeeded with some difficulty in cloning the DNA encoding the HCV receptor and have discovered, surprisingly that the DNA encodes a cellular protein known as CD81. We are not aware of any association in the literature between CD81 and the HCV. CD81 was first identified by monoclonal antibodies as the target of an antiproliferative antibody (TAPA-1) which inhibited *in vitro* cellular proliferation. Armed with this new information and given the sequence knowledge of CD81 in the public databases it is now possible to design and produce an armoury of therapeutic and diagnostic reagents against HCV.

#### Summary of the Invention

20

According to the present invention, there is provided a CD81 protein, or functional equivalent thereof, for use in the therapy or diagnosis of hepatitis C (HCV). According to a further aspect of the present invention there is provided a compound that binds specifically to the CD81 protein for use in the therapy or diagnosis of HCV.

25

The term "CD81 protein, or a functional equivalent thereof" as used herein means the CD81 protein as defined by the protein sequence listed in the SWISSPROT database (Accession No. P18582) or the EMBL/GENBANK database (Accession No. M33690) or a functional equivalent thereof. A functional equivalent of CD81 is a compound which is capable of binding to HCV, preferably to the E2 protein of HCV. Preferably, the functional equivalent is a peptide or protein. The term "functional equivalent" includes an analogue of CD81 or a fragment of CD81.

30

The term "a functionally equivalent fragment" as used herein means any fragment or assembly of fragments of the complete protein. For example, the complete protein may be truncated at one or both ends or domains may be removed provided the protein retains the defined function. For example, one or more regions of the protein responsible for membrane binding may be removed to render the protein soluble when produced by a recombinant process. The fragment of choice comprises the extracellular loop 2 of the CD81 protein (amino acids 113-201).

The term "a functionally equivalent analogue" is used to describe those compounds that possess an analogous function to an activity of the CD81 protein and may, for example comprise a peptide, cyclic peptide, polypeptide, antibody or antibody fragment. These compounds may be proteins, or may be synthetic agents designed so as to mimic certain structures or epitopes on the inhibitor protein. Preferably, the compound is an antibody or antibody fragment.

If proteinaceous, functionally equivalent fragments or analogues may belong to the same protein family as the CD81 protein identified herein. By "protein family" is meant a group of proteins that share a common function and exhibit common sequence homology. By sequence homology is meant that the protein sequences are related by divergence from a common ancestor, such as is the case between the human and the chimpanzee. Chimpanzee CD81 is thus an example of a functionally equivalent protein. Preferably, the homology between functionally equivalent protein sequences is at least 50% across the whole of amino acid sequence of the protein or protein fragment. More preferably, the homology is at least 75% across the whole of amino acid sequence of the protein or protein fragment. Most preferably, homology is greater than 80% across the whole of the sequence.

The term "functionally equivalent analogue" includes any analogue of CD81 obtained by altering the amino acid sequence, for example by one or more amino acid deletions, substitutions or additions such that the protein analogue retains the ability to bind to HCV, preferably the E2 protein of HCV. Amino acid substitutions may be made, for example, by point mutation of the DNA encoding the amino acid sequence.

The functional equivalent of CD81 may be an analogue of a fragment of CD81. The CD81 or functional equivalent may be chemically modified, provided it retains its ability to bind to HCV, preferably the E2 protein of HCV.

- 5 It is envisaged that such molecules will be extremely useful in preventative therapy of HCV infection, because these molecules will bind specifically to the CD81 receptor molecule and will prevent internalisation of the virus into cells. By binding "specifically" to the CD81 protein it is meant that the compound has high affinity for the CD81 protein and does not bind to any other protein with similar high affinity.
- 10 Accordingly, when introduced into a mammalian subject, this compound will only bind with high affinity to the CD81 protein.

- The CD81 protein, or functional equivalent thereof may be produced by any suitable means, as will be apparent to those of skill in the art. In order to produce sufficient
- 15 amounts of CD81 protein, or functional equivalents thereof for use in accordance with the present invention, expression may conveniently be achieved by culturing under appropriate conditions recombinant host cells containing the CD81 protein, or functional equivalent thereof.

- 20 Systems for cloning and expression of a polypeptide in a variety of different host cells are well known.

- Two preferred methods of construction of carrier proteins according to the invention are direct chemical synthesis and by production of recombinant protein. Preferably, the
- 25 CD81 protein is produced by recombinant means, by expression from an encoding nucleic acid molecule. Recombinant expression has the advantage that the production of the protein is inexpensive, safe, facile and does not involve the use of toxic compounds that may require subsequent removal.

- 30 When expressed in recombinant form, the CD81 protein is preferably generated by expression from an encoding nucleic acid in a host cell. Any host cell may be used, depending upon the individual requirements of a particular system. Suitable host cells include bacteria, mammalian cells, plant cells, yeast and baculovirus systems.



Mammalian cell lines available in the art for expression of a heterologous polypeptide include Chinese hamster ovary cells, HeLa cells, baby hamster kidney cells and many others. Preferably, bacterial hosts are used for the production of recombinant protein, due to the ease with which bacteria may be manipulated and grown. A common, preferred bacterial host is *E. coli*.

Preferably, if produced recombinantly, the CD81 protein or functional equivalent is expressed from a plasmid that contains a synthetic nucleic acid insert. The insertion site in the expression plasmid into which the nucleic acid encoding the CD81 protein or functional equivalent is cloned may allow linkage of the protein to a tag, such as the "flag" peptide or polyhistidine. This arrangement facilitates the subsequent purification of recombinant protein.

According to a further aspect of the present invention, there is also provided a nucleic acid molecule encoding the CD81 protein or functional equivalent thereof, for use in the therapy or diagnosis of HCV infection. As will be apparent to one of skill in the art, such a nucleic acid molecule will be designed using the genetic code so as to encode the protein or peptide that is desired. A nucleic acid molecule according to this aspect of the present invention may comprise DNA, RNA or cDNA and may additionally comprise nucleotide analogues in the coding sequence. Preferably, the nucleic acid molecule will comprise DNA.

Nucleotide sequences included within the scope of this embodiment of the invention are those hybridising to nucleic acid encoding the CD81 protein under standard conditions. Preferably, such modified nucleic acid molecules will retain the ability to hybridise specifically to nucleic acid encoding CD81 or a fragment thereof and will include nucleic acid sequences with 40% homology across the whole of nucleotide sequence. More preferably, the homology is at least 65% across the whole of the nucleotide sequence. Most preferably, homology is greater than 70% across the whole of the sequence.

Nucleic acid encoding the CD81 protein or functional equivalent may be cloned under the control of an inducible promoter, so allowing precise regulation of protein expression. Suitable inducible systems will be well known to those of skill in the art.

- 5 Suitable vectors for the expression of the CD81 protein or functional equivalent may be selected from commercial sources or constructed in order to suit a particular expression system. Such vectors will contain appropriate regulatory sequences, such as promoter sequences, terminator sequences, polyadenylation sequences, enhancer sequences and marker genes. Vectors may be plasmids, or viral-based. For further details see
- 10 Molecular Cloning: a laboratory manual (Sambrook *et al.*, 1989). Many known techniques and protocols for the manipulation of nucleic acids and analysis of proteins are described in detail in "Short protocols in molecular biology", second addition, Ausubel *et al.* (John Wiley & Sons 1992).
- 15 Methods for the isolation and purification of recombinant proteins will be well known to those of skill in the art and are summarised, for example in Sambrook *et al.* (1989). Particularly in bacteria such as *E. coli*, the recombinant protein will form inclusion bodies within the bacterial cell, thus facilitating its preparation. If produced in inclusion bodies, the carrier protein may need to be refolded to its natural conformation.
- 20 Additionally, in order to tailor precisely the exact properties of the CD81 protein or functional equivalent thereof, the skilled artisan will appreciate that changes may be made at the nucleotide level from known CD81 sequences, by addition, substitution, deletion or insertion of one or more nucleotides. Site-directed mutagenesis (SDM) is the
- 25 method of preference used to generate mutated proteins according to the present invention. There are many techniques of SDM now known to the person of skill in the art, including oligonucleotide-directed mutagenesis using PCR as set out, for example by Sambrook *et al.*, (1989) or using commercially available kits.
- 30 Suitable vectors can be chosen or constructed, containing appropriate regulatory sequences, including promoter sequences, terminator sequences, polyadenylation sequences, enhancer sequences, marker genes and other sequences as appropriate. Vectors may be plasmids, viral e.g. 'phage, or phagemid, as appropriate. For further

details see, for example, *Molecular Cloning: a Laboratory Manual*: 2nd edition, Sambrook *et al.*, 1989, Cold Spring Harbor Laboratory Press. Many known techniques and protocols for manipulation of nucleic acid, for example in preparation of nucleic acid constructs, mutagenesis, sequencing, introduction of DNA into cells and gene  
5 expression, and analysis of proteins, are described in detail in *Short Protocols in Molecular Biology*, Second Edition, Ausubel *et al.* eds., John Wiley & Sons, 1992. The disclosures of Sambrook *et al.* and Ausubel *et al.* are incorporated herein by reference.

10 According to a further aspect of the invention, there is provided a method for treating an infection of HCV comprising administering to a patient a therapeutically effective amount of CD81 protein, or a functional equivalent thereof effective to reduce the infectivity of the virus.

15 Since the infection mechanism of HCV appears to depend, in part, upon the availability of a cell surface receptor, making available a soluble form of the CD81 protein, or a functional equivalent thereof will act as an antagonist of binding of HCV to the cellular receptor thus reducing or preventing the infection process and thereby treating the disease.

20 A suitable soluble form of the CD81 protein, or a functional equivalent thereof might comprise, for example, a truncated form of the protein from which the transmembrane domain or domains have been removed either by a protein cleavage step or, by design, in a chemical or recombinant DNA synthesis.

25 Alternatively, a hybrid particle comprising at least one particle-forming protein, such as hepatitis B surface antigen or a particle-forming fragment thereof, in combination with the CD81 protein or functional equivalent thereof could be used as an antagonist of binding of HCV to the cellular receptor.

30 According to a still further aspect of the invention, there is provided a method for treating an infection of HCV comprising administering to a patient a therapeutically effective amount of a compound that specifically binds to CD81 protein. The rationale

behind this therapeutic strategy is that the binding of the cell surface receptor to another compound will prevent the binding of HCV to the receptor, so preventing the infection process and thereby treating the disease.

- 5 According to a further aspect of the invention, there is provided a pharmaceutical composition comprising a CD81 protein or functional equivalent thereof, optionally as a pharmaceutically acceptable salt, in combination with a pharmaceutically acceptable carrier. According to a still further aspect of the present invention there is provided a pharmaceutical composition comprising a compound that binds specifically to the CD81  
10 protein, optionally as a pharmaceutically acceptable salt, in combination with a pharmaceutically acceptable carrier.

The pharmaceutical composition may be in any appropriate form for administration including oral, parenteral and transdermal compositions. The composition may be  
15 administered alone or in combination with other treatments, either simultaneously or sequentially dependent upon the condition to be treated.

A process is also provided for making the pharmaceutical composition, in which a protein of the present invention is brought into association with a pharmaceutically  
20 acceptable carrier.

According to a further aspect of the invention, there is provided a CD81 protein or functional equivalent thereof, or a compound that binds specifically to the CD81 protein for use as a pharmaceutical.  
25

According to a further aspect of the invention, there is provided the use of a CD81 protein or functional equivalent thereof or compound that binds specifically to the CD81 protein in the manufacture of a medicament for the treatment of an HCV infection.  
30

The ability of a CD81 protein or functional equivalent thereof to bind to HCV permits the use of the protein as a diagnostic for HCV infection, for example in an ELISA or RIA.

A soluble form of the protein could, for example, be used in an ELISA form of assay to measure neutralising antibodies in serum. More preferably, antibodies to CD81 will be suitable for use in this context, since these molecules will be anti-idiotypic antibodies  
5 for HCV itself.

According to a further aspect of the invention, there is provided an assay for HCV antibodies in a serum sample comprising the step of allowing competitive binding between antibodies in the sample and a known amount of an HCV protein for binding to  
10 a CD81 protein or functional equivalent thereof and measuring the amount of the known HCV protein bound.

Preferably, the CD81 protein or functional equivalent thereof is immobilised on a solid support and the HCV protein, which may suitably be E2 HCV envelope protein,  
15 optionally recombinant E2 protein, is labelled. The label may be a radioactive label, a peptide, an epitope, an enzyme, or any other bioactive compound. Preferably the label comprises an enzyme.

In an assay of this form, competitive binding between antibodies and the HCV protein  
20 for binding to the CD81 protein or functional equivalent thereof results in the bound HCV protein being a measure of antibodies in the serum sample, most particularly, HCV neutralising antibodies in the serum sample.

A significant advantage of the assay is that measurement is made of neutralising  
25 antibodies directly (i.e. those which interfere with binding of HCV envelope protein to the cellular receptor). Such an assay, particularly in the form of an ELISA test has considerable applications in the clinical environment and in routine blood screening.

Also, since the assay measures neutralising antibody titre, the assay forms a ready  
30 measure of putative vaccine efficacy, neutralising antibody titre being correlated with host protection.

In a further aspect of the invention, there is provided a diagnostic kit comprising the CD81 protein or functional equivalent thereof. Preferably the kit also contains at least one labelled HCV protein, optionally enzyme labelled. The kit will also contain other components necessary for the analysis of the presence of HCV or anti-HCV antibodies  
5 in serum. Such components will be readily apparent to those of skill in the art.

The CD81 protein or functional equivalent thereof may be used to screen for chemical compounds mimicking the HCV surface structure responsible for binding to the HCV receptor.

10

According to a further aspect of the invention, there is provided a method for screening chemical compounds for ability to bind to the region of HCV responsible for binding to a host cell, comprising measuring the binding of a chemical compound to be screened to a CD81 protein or functional equivalent thereof. The host cell may be any mammalian  
15 cell, preferably a human host cell.

This aspect of the invention encompasses the products of the screening process whether alone, in the form of a pharmaceutically acceptable salt, in combination with one or more other active compounds and/or in combination with one or more pharmaceutically  
20 acceptable carriers. Processes for making a pharmaceutical composition are also provided in which a chemical compound identified by the process of the invention is brought into association with a pharmaceutically acceptable carrier.

The chemical compound may be an organic chemical and may contain amino acids or  
25 amino acid analogues. Preferably however the chemical compound is a peptide, polypeptide or a polypeptide which has been chemically modified to alter its specific properties, such as the affinity of binding to the CD81 protein or functional equivalent thereof or its stability *in vivo*.

30 According to a further aspect of the invention, there is provided a nucleic acid encoding CD81 protein or functional equivalent thereof for use in diagnosis or therapy of HCV. The nucleic acid may encode any part of the CD81 protein, or functional equivalent thereof. According to a still further aspect of the present invention, there is provided a

nucleic acid encoding a peptide or polypeptide compound that binds specifically to CD81.

Changes to the nucleic acid may be made at the nucleotide level by addition,  
5 substitution, deletion or insertion of one or more nucleotides, which changes may or  
may not be reflected at the amino acid level, dependent on the degeneracy of the genetic  
code. Hybridising sequences included within the scope of this embodiment of the  
invention are those binding under standard conditions. Preferably, such modified nucleic  
acid molecules will retain the ability to hybridise specifically to nucleic acid encoding  
10 CD81 or a fragment thereof and will include nucleic acid sequences with 40%  
homology across the whole of nucleotide sequence. More preferably, the homology is  
at least 65% across the whole of the nucleotide sequence. Most preferably, homology is  
greater than 70% across the whole of the sequence.

15 As used herein, standard conditions includes both non-stringent standard hybridisation  
conditions (6 x SSC/50% formamide at room temperature) with washing under conditions  
of low stringency (2 x SSC/50% formamide at room temperature, or 2 x SSC, 42°C) or at  
standard conditions of higher stringency, e.g. 2 x SSC, 65°C (where SSC = 0.15M NaCl,  
0.015M sodium citrate, pH 7.2). Preferably the term standard conditions refers to  
20 conditions of high stringency.

The nucleic acid may be included in a vector, optionally an expression vector permitting  
expression of the nucleic acid in a suitable host to produce CD81 protein or functional  
equivalent thereof.

25

The identification of the DNA encoding the HCV receptor, namely CD81, makes  
available the full power of molecular biology for the molecular analysis of HCV and in  
particular its infectious mechanism, offering for the first time the possibility of  
designing methods of treating the virus. PCR methods may be used to identify cells  
30 carrying the receptor and DNA molecules may be designed to act as polymerase chain  
reaction (PCR) primers in this connection. Although CD81 is widespread and is  
associated with normal human function, the present invention includes antisense

molecules inhibiting CD81 production for use in the treatment of HCV and in the manufacture of a medicament for the treatment of HCV infection.

5 The identification of polymorphisms in the CD81 protein may be found to be associated with susceptibility to HCV infection or likely prognosis. Accordingly, the identification of the gene encoding the HCV receptor allows the evaluation of polymorphisms present throughout the human population.

10 According to a further aspect of the invention, there is provided an antibody to CD81 protein or functional equivalent thereof for use in the treatment of an HCV infection and in the manufacture of a medicament for the treatment of an HCV infection. The antibody is preferably a monoclonal antibody. Such an antibody can be used to temporarily block the CD81 receptor preventing infection from HCV, for example, immediately after an accidental infection with HCV-infected blood.

15 At present, the only available animal model of HCV infection is the chimpanzee, which is a protected species. Experiments on such animals pose a number of difficulties which together result in a very considerable expense (a one year experiment with one chimpanzee can cost \$70,000). Compared to this, a mouse model would be far more acceptable. Unfortunately, as described below the HCV receptor, whilst ubiquitous in  
20 humans and found in chimpanzees, is absent in other mammals. A transgenic mammal, for example a mouse, carrying the HCV receptor on the cell surface, perhaps expressed in greater or lesser amounts than normally found, would be of great benefit to HCV research and the development of vaccines. Expression of mutant CD81 proteins on the  
25 surface of cells would also be a useful research tool.

According to a further aspect of the invention, there is provided a transgenic non-human animal, suitably a mammal such as a mouse, carrying a transgene encoding a CD81 protein or functional equivalent thereof.

30

The transgenic animal of the invention may carry one or more other transgenes to assist in maintaining an HCV infection.



There is also provided a process for producing a transgenic animal comprising the step of introducing a DNA encoding a CD81 protein or functional equivalent thereof into the embryo of a non-human mammal, preferably a mouse.

- 5 Preferably the CD81 protein or functional equivalent thereof is a human CD81.

According to a further aspect of the present invention, there is provided a CD81 protein or a functional equivalent thereof for use as a protective immunogen in the control of HCV.

10

#### Brief Description of the Drawings

Figure 1A is a schematic description of primary, secondary and tertiary rounds of screening.

15

Figure 1B is a schematic description of the final round of screening.

Figure 2 is a FACS scan analysis of E2 bound cells.

- 20 Figure 3 shows the dose-dependent inhibition of anti CD81 binding to B cells by recombinant E2. The data are expressed as % inhibition of mean fluorescence intensity.

- Figure 4 is an immunoblot showing the recognition of the membrane protein fraction immunoprecipitated by anti-CD81 antibody. Lane 2: recombinant E2 precipitated with chimpanzee antiserum to E2; lane 3, recombinant E2 precipitated with chimpanzee pre-immune serum lane 4: 20µg of anti-CD81 mAb (clone JS81 Pharmingen) precipitated with goat anti-mouse IgG, lane 5: control, (20 µg of an irrelevant monoclonal antibody, anti-human CD9, ATCC) precipitated with goat anti-mouse IgG linked to protein A sepharose. Lane 1: positive control, membrane protein preparation.

30

Figure 5 shows the nucleotide and deduced amino acid sequences of the EC2 fragment cloned in pThio-His C and the upstream plasmid sequence coding for the carboxyl terminus of thioredoxin and for the enterokinase cleavage site.

Figure 6 shows the appearance of a protein band of the expected molecular mass for thioredoxin-EC2 in the extract from the induced sample.

- 5 Figure 7 is a Coomassie Blue stained gel showing the purification of thioredoxin-EC2.

Figure 8 represents the nucleotide and deduced amino acid sequence of the EC2-His<sub>6</sub> fragment cloned into pGEX-KG as well as the upstream plasmid sequence coding for the carboxyl terminus of GST, the thrombin cleavage site and a small glycine spacer.

10

Figure 9 represents an SDS-PAGE of total proteins of the TOP10 *E. coli* clone which express GST-EC2-(His)<sub>6</sub>.

- 15 Figure 10 is a Coomassie-stained SDS-PAGE showing thrombin cleavage of GST-EC2-(His)<sub>6</sub> after purification of the protein on a glutathione sepharose column.

Figure 11 shows the dose-dependent inhibition of E2 binding to hepatocarcinoma cells by recombinant molecule expressing the major extracellular loop (EC2) of human CD81.

20

Figure 12 shows binding of HCV to CD81.

### Detailed Description of the Invention

- 25 **Example 1. Recombinant E2, cell lines, vector DNA, and antibodies used in the present study.**

30 The recombinant E2 used in this screening was produced in CHO cells (E2-CHO) (WO 97/09349). E2-CHO binds to the human T cell lymphoma cell line Molt-4. A subline of Molt-4 (termed A2A6), was identified by expanding individual Molt-4 cell colonies and testing for the amount of E2-CHO that bound to the cell surface. The A2A6 subline was found to bind more E2-CHO molecule on its surface than its parental line and was therefore chosen for the source of RNA, expecting that this subline may have a higher

representation of the transcript encoding the E2 binding molecule. These cells were chosen using an assay whereby human B and T lymphoma cells and hepatocarcinoma cell lines were incubated with recombinant E2 expressed in mammalian cells (CHO) as described by D. Rosa *et al.*, *Proc. Natl. Acad. Sci. USA* 93, 1759 (1996) and stained  
 5 with biotin-labelled anti-E2 antibodies as described by Rosa *et al.*, (1996). Cells with the highest E2 binding ability were sorted using a FacsVantage (Becton Dickinson) and subcloned by limiting dilution. Growing clones were screened for E2 binding at the Facs and clones with the highest Mean Fluorescence Intensity were further expanded.

- 10 WOP is a NIH3T3-derived cell which expresses polyoma T antigen (L. Dailey and C. Basilico, *J. Virol.* 54, 739 (1985). In this cell line, plasmids containing the polyoma replication origin can be amplified episomally. Recombinant DNA constructed with pCDM8 (Invitrogen) can be recovered from selected transfectants, which contains the polyoma replication origin and is designed for the manipulation of expression libraries  
 15 in eukaryotic cells.

A mouse monoclonal anti-E2 antibody (291A2) was used for detection of E2-CHO bound on the cell surface of transfectants. This antibody was obtained as follows: BALB-c mice were immunised three times with recombinant E2 (10µg) in complete  
 20 Freund's adjuvant. Cell fusions between spleen cells and non-producing myeloma cells were made according to standard techniques. The supernatant from fusions was then screened for binding to E2 bound to Molt-4 cells, so as to identify monoclonal antibodies that bound to an exposed site on the E2 molecule. The most suitable antibody identified in this fashion was termed 291A2.

25

### **Example 2: Construction of cDNA library**

Total RNA was extracted from the A2A6 cell line according to the method described by Chomczynsky and Sacchi (Chomczynsky, P. And Sacchi, N. *Anal Biochem.* 162: 156-  
 30 159, 1987.). Poly(A)+ was enriched twice using oligo(dT) cellulose. Starting from 2µg of this RNA as a template, the double strand complementary DNA was synthesized using a Superscript II cDNA synthesis kit (Life Technologies) in the presence of oligo(dT) (100ng) and random hexamer primers (100ng). The cDNA was blunt-ended

with T4 DNA polymerase, and was ligated with a *Bst*XI linker, which allows the insertion of the fragment into the same restriction site in the polylinker region of the expression vector pCDM8. The linker-ligated cDNA was phenol-extracted and ethanol precipitated using ammonium sulphate to remove free mononucleotides, followed by  
 5 Sephacryl 500 chromatography (Lifetechnologies) to size-fractionate the cDNA. The purified cDNA fragment over 500bp were pooled and ligated with *Bst*XI - digested pCDM8 at a molecular ratio of approximately 1:1. This final ligation reaction was used from transformation of *E. coli* MC1061/P3 by electroporation using Gene-Pulser (BIORAD). A total of  $2 \times 10^6$  cfu was amplified and pooled in liquid bacterial culture as  
 10 a cDNA library.

### Example 3: Library screening

The screening procedure was based largely on the method described by Campbell *et al.*  
 15 (Campbell, I. G., Jones, T.A., Foulkes, W. D. And Trowsdale, J. Cancer Res. 51: 5329-5338, 1991). Enrichment was carried out using magnetic beads (the first to the third round) (Figure 1A) and panning techniques (the fourth round). (Figure 1B).

#### 3.1 The first round of screening

20 A total of 375µg of amplified DNA, which represents  $2 \times 10^6$  of independent cDNA clones, was prepared. In each transfection, 25µg of DNA was mixed with  $10^7$  WOP cells using the Gene-Pulser electroporator (BIORAD) under the conditions of 300V/500µF. Fifteen sets of transfections were performed. After transfection, cells  
 25 were incubated at 37°C for 2 days and then the cells were detached by trypsinization and washed with PBS supplemented with 5% FCS and 0.5mM EDTA twice by centrifugation at 360g for 10min at 4°C. The cell pellet was resuspended in PBS supplemented with 5% FCS and 0.5mM EDTA ( $10^7$  cells/ml) and then E2-CHO was added to the cell suspension at a concentration of 10µg/ml. The cells were incubated on  
 30 ice for 60 min. After washing twice with PBS supplemented with 5% FCS and 0.5mM EDTA, the cell suspension was incubated with 291A2 antibody on ice for 30 min. After washing twice with PBS supplemented with 5% FCS and 0.5mM EDTA, 10µl of Dynabeads (DYNAL) coupled with goat anti-mouse IG was added to the cell

suspension. The mixture was gently agitated using a Coulter Mixer (Coulter) for 60 min at 4°C. Bound cells were separated using Magnetic Particle Concentrator (DYNAL) from non-binders, according to the manufacturer's instructions, thus enriching E2-binding transfectants. Plasmid DNA was recovered from the bound  
5 transfecting cells using the protocol described by Campbell *et al.* (Campbell, I. G., Jones, T.A., Foulkes, W. D. And Trowsdale, J. Cancer Res. 51: 5329-5338, 1991). *E. coli* MC1061/P3 was transformed with this plasmid by electroporation. This DNA pool is referred to as the first enriched pool (1°EP).

### 10 3.2 The second round of screening

A total of 150µg of amplified DNA derived from 1°EP was prepared and 6 sets of the transfection were performed and transfectants were enriched using the same condition as in the first screening. This DNA pool is referred to as 2°EP.

15

### 3.3 The third round of screening

A total of 25µg of amplified DNA derived from 2°EP was prepared and one set of the transfection was performed. Transfectants were enriched using the same condition as in  
20 the first screening. During this separation step, transfectants formed aggregates, which might be caused by expression of irrelevant adhesion molecules. This could decrease the efficiency of enrichment because these aggregates contained magnetic beads non-specifically. To circumvent this potential problem, transfectants after the second separation by Magnetic Particle Concentrator were diluted and plated on Terasaki  
25 plates. Approximately 100 of single cells identified under microscope were pooled and plasmid DNA was extracted from them. The DNA pool prepared from this step is referred to as 3°EP.

30

### 3.4 The fourth round of screening

291A1 monoclonal antibody was incubated in a Petri dish (90mm) at a concentration of 10µg/ml overnight at 4°C.

A total of 25µg of amplified DNA derived from 3°EP was prepared and one set of transfections was performed. The transfected cells were incubated with E2-CHO as described above, and placed onto the 291A2-coated plates for 60 min at 4°C. After rinsing with a large excess of PBS supplemented with 5% FCS and 0.5mM EDTA twice, the bound cells were directly treated with the lysing solution and plasmids were extracted as described as before. This DNA pool is referred to as 4°EP.

#### 3.4 Identification of cDNA encoding a molecule binding to the recombinant E2

DNA was isolated from single colonies derived from 4°EP. A single transfection was performed for each plasmid preparation using the same conditions as used for the previous screening steps. E2-binding of the transformants was detected using a phycoerythrin-conjugated monoclonal Fab fragment of goat anti-mouse Ig instead of the antibody-coupled Dynabeads. Transfectants of 3°EP and 4°EP were also analyzed in the same way. The E2-bound cells were detected on FACScan (Becton Dickinson) and analyzed with LYSIS II program (Becton Dickinson) (Figure 2). E2-CHO binds increasingly as the purification step advances. A single clone P3 showed strong E2-binding.

#### **Example 4: DNA sequencing determination and analysis.**

P3 contains a insert of approximately 1 kb. The DNA sequence of the insert of the cDNA clone which confers E2-binding to WOP upon transfection was determined by an automated sequencing system using the T7 primer, whose sequence is located adjacent the cloning site of pCDM8. The sequence was screened through the GenBank databases using the GCG programs on a UNIX computer. This analysis revealed that the 5' part of P3 insert is identical to human CD81 (TAPA-1). Restriction analysis of P3 using three enzymes (*Bst*XI), *Hinc*II and *Nco*I also agreed with the restriction map of human CD81 cDNA.

### Example 5: Binding of CD81 to recombinant E2.

5

Anti-CD81 antibodies were used to assess the interaction between E2 and CD81. EBV-B cells were incubated with increasing concentrations of recombinant E2 for 1 hour at 4°C and then stained with an anti-CD81 monoclonal antibody (clone JS-81, Pharmingen). As shown in Figure 3, recombinant E2 was found to competitively inhibit  
 10 the binding of anti-CD81 antibodies to EBV transformed B-cell lines (EBV-B cells). The data are expressed as % inhibition of mean fluorescence intensity (Rosa *et al.*, 1996).

In addition, E2 reacts in Western blot with anti-CD81 precipitated material (Figure 4).  
 15 This Figure shows E2 recognition of membrane protein fraction immunoprecipitated by anti-CD81 antibody. Approximately 300 µg of membrane protein extract prepared from the A2A6 cell line were solubilised in 8mM CHAPS in PBS pH 7.4, incubated with 10 µg recombinant E2 (lanes 2 and 3), with 20µg of anti-CD81 mAb (clone JS81; Pharmingen) (lane 4), or as control, with 20 µg of an irrelevant monoclonal antibody  
 20 (anti-human CD9, ATCC) (lane 5) for 2 hours at 4°C, and finally precipitated with chimpanzee antiserum to E2 (lane 2), chimpanzee pre-immune serum (lane 3), or goat anti-mouse IgG (lanes 4 and 5) bound to protein A sepharose (CL-4B, Pharmacia). The pellet was dissolved in Laemmli buffer and subjected to SDS-PAGE under non-reducing conditions. After electroblotting, the PVDF membrane (Millipore) was  
 25 incubated overnight with 1µg/ml of recombinant E2 at room temperature, and for 2 hours with 291A2 anti-E2 monoclonal antibody. E2 binding to immunoprecipitated proteins was detected with an anti-mouse IgG peroxidase-conjugated polyclonal antibody (Amersham). As a positive control membrane proteins also were loaded on the gels (lane 1). The mobility of molecular weight standards is indicated on the left in  
 30 kilodaltons.

CD81 is also expressed on fresh lymphocytes and hepatocytes as demonstrated by immunohistochemical staining with biotin-labelled-E2 or anti-CD81 (data not shown).

To assess whether CD81 could mediate the internalisation of ligands, we exploited the fact that CD81 forms a complex with CD19 and CD21 on the surface of B lymphocytes (D. T. Fearon and R. H. Carter, 1995, *Annu. Rev. Immunol.* 13, 127). B cells were incubated with E2 at 37°C for different times, after which CD19 or CD21 levels on the cell surface were measured by immunofluorescence. Incubation of B cells with E2 resulted in down-regulation of both CD19 and CD21 (data not shown). It thus seems as if CD81 is able to mediate the internalisation of both these ligands.

#### 10 **Example 6: The major extracellular loop of CD81 binds recombinant E2 and viral particles.**

To map the CD81 domain that binds E2 protein our efforts were focused on the EC2 hydrophilic extracellular loop of the protein. This fragment was expressed in *E. coli* as a Thioredoxin-EC2 fusion protein that has an enterokinase site between thioredoxin and EC2, and as a GST-EC2 fusion protein which has a thrombin site between GST and EC2 and a hexa-histidine tag added to the carboxyl-terminus of the protein. We show that both proteins are expressed and are able to bind HCV E2. In competition experiments we also show that the purified fusion proteins and the EC2-His fragment excised from GST-thrombin-EC2-(His)<sub>6</sub> are able to inhibit the binding of E2 on the surface of CD81 expressing cells.

##### 6.1 Cloning of EC2 in pThio-His.

Figure 5 shows the nucleotide and the deduced amino acid sequences of the EC2 fragment cloned in pThio-His C and the upstream plasmid sequence coding for the carboxyl terminus of thioredoxin and for the enterokinase cleavage site. As shown, EC2 is fused in frame with thioredoxin through the enterokinase site, which can be exploited to remove thioredoxin from the fusion protein.

30 The fragment coding for EC2 was PCR-amplified from the plasmid pCDM8/P3 using the following oligodeoxynucleotides:



Forward BL

EC2

5'GGCGGGGGTGGATCCGGGGGTGGAGGCTCGAGCTTTGTCAACAAGGACC-  
3'

*XhoI* Phe Val Asn Lys Asp

5 Reverse BL EC2

5'CCCCAAGCTT TCA CAG CTT CCC GGA GAA GAG GTC ATC G3'

*HindIII* Stop Leu Lys Gly Ser Phe Leu Asp Asp

Using standard cloning techniques (Sambrook *et al.*, 1989) the PCR product was  
10 double-digested with *XhoI* and *HindIII*, ligated to pThio-His C (Invitrogen) digested  
with the same restriction enzymes, and transformed into Top10 *E. coli* cells. After  
selection of the transformants by restriction enzyme analysis and DNA sequencing of  
the plasmids, a correct construct coding for the expected thioredoxin-EC2 fusion  
protein was identified. Glycerol batches of selected clones were stored to -  
15 80°C.

Total protein extracts of the thioredoxin-EC2 expressing clone before and after IPTG  
addition, were subjected to SDS-PAGE to analyse protein expression. Figure 6 clearly  
shows the appearance of a protein band of the expected molecular mass (23.4 kDa) in  
20 the extract from the induced sample. The figure also shows the reactivity of the fusion  
protein with E2. The TOP10 *E. coli* clone containing the pThio-hisC-EC2 plasmid and  
a TOP10 clone containing the pThio-HisC plasmid devoid of insert were induced,  
soluble protein extracts were prepared from both clones and subjected to Far Western  
Blot with E2 protein. For this blot, protein samples were brought to 1x loading sample  
25 buffer (LSB) (5% w/v SDS, 10% v/v glycerol, 62.5 mM Tris-HCl, 0.05 %  
Bromophenol Blue) using a 3x LSB solution. The samples were run onto a 15%  
polyacrylamide gel and transferred to a PVDF membrane (Immobilon-P, Millipore).  
The membrane was incubated for 30 min in blocking solution (PBS, 10% w/v non-fat  
dried milk, 0.05% v/v Tween 20). Following an incubation of 15 hours at 4°C with  
30 blocking solution containing 1 µg/ml of CHO-E2, the membranes were incubated for 2  
hours with the 291-A2 anti-E2 monoclonal antibody diluted 1:250, and for 1 hour with a  
peroxidated goat antimouse Ig antibody (Sigma) diluted 1:2000. Three washing steps  
between all incubation steps were performed using blocking solution, which was also

used to dilute the antibodies. After a final wash with PBS the membranes were incubated for 1 min with luminol (ECL, Amersham) and exposed on Hyper-film (Amersham).

- 5 As can be seen from these Figures, a band corresponding to the molecular weight of Thioredoxin-EC2 was visible in the lane where the soluble proteins from the pThio-HisC-EC2 were loaded. Such a band was absent in the lane where the soluble proteins of the pThio-HisC clone were loaded.

10 6.2 Purification of Thioredoxin-EC2

For the purification of thioredoxin-EC2 the following procedure was developed: 1) osmotic shock of the cells, 2) protein precipitation with 30% saturation ammonium sulphate, and 3) IMAC. After osmotic shock about 50% of the fusion protein was  
15 released from the cells together with contaminant proteins. The ammonium sulphate precipitation resulted in a pellet which contained thioredoxin-EC2 devoid of the bulk of contaminant proteins. IMAC of the resuspended precipitate resulted in a fusion protein which was about 85% pure. With this procedure we purified 5 mg thioredoxin-EC2 from a litre of culture. This procedure is set out in detail below.

20

The *E. coli* clone expressing Thioredoxin-EC2 was inoculated in 500 ml LB medium containing 100 µg/ml ampicillin. At  $OD_{600} = 0.5$ , 0.5 mM IPTG was added to the culture and growth was continued at 37°C for additional 3.5 hours. The culture was then centrifuged at 4000 g for 10 min at 4°C, the cell pellet was resuspended with 50 ml  
25 ice cold hypertonic solution (20 mM Tris-HCl, 2.5 mM EDTA, 20 % sucrose, pH 8) and left on ice for 10 min. The resuspended cells were centrifuged again as above and the pellet was resuspended in hypotonic buffer (20 mM Tris-HCl, 2.5 mM EDTA, pH 8) to osmotically shock the cells. After 20 min at 0°C the suspension was centrifuged at 12.000 g for 10 min at 4°C, the supernatant was brought to 30%  $NH_2(SO_4)_2$  using a  
30 room temperature saturated solution of the salt. The suspension was incubated overnight at 4°C and then centrifuged at 10.000 g for 10 min. The pellet was resuspended using 15 ml of 20 mM Phosphate buffer, 500 mM NaCl, pH 6, clarified by centrifugation, and loaded on a 2 ml column of Nickel activated Chelating Sepharose Fast Flow (Pharmacia) equilibrated in the same buffer.

After adsorption, the column was washed with 10 ml of the equilibrium buffer (flow rate 0.5 ml/min), and then the Thioredoxin-EC2 was eluted using a 30 ml gradient 0-50 mM Imidazole in 20 mM Phosphate buffer, 500 mM NaCl, pH 6 followed by an isocratic elution with 10 ml of 400 mM imidazole. 2.4 ml fractions were collected. The fractions containing the recombinant protein were pooled, dialysed against PBS, and stored to -20 °C. Proteins were analysed by means of SDS-PAGE and protein content was assayed by the Bradford method using BSA as a protein standard.

10 Purified Thioredoxin-EC2 is shown in Figure 7.

### 6.3 Cloning of EC2-(His)<sub>6</sub> in pGEX-KG

Figure 8 represents the nucleotide and deduced aminoacidic sequence of the EC2-(His)<sub>6</sub> fragment cloned in pGEX-KG as well as the upstream plasmid sequence coding for the carboxyl terminus of GST, the thrombin cleavage site, and a small glycine spacer. As shown, EC2 is fused in frame with GST through the thrombin site, which can be exploited to remove GST from the fusion protein. The glycine-rich spacer, located between thrombin site and EC2, facilitates the cleavage of the fusion protein by thrombin (Guan, K.L., and Dixon, J.E. (1991) *Anal. Biochem.* **192**, 262-267).

The fragment coding for EC2 was PCR-amplified from the plasmid pCDM8/P3 using the following oligodeoxynucleotides:

25            EC2 Forward            EC2  
              5' CAAAAGGAATTCTA TTT GTC AAC AAG GAC CAG ATC GCC AAG3'  
                          EcoRI            Phe Val Asn Lys Asp Gln Ile Ala Lys

                 Reverse BLH                            His tag                            EC2

30            5'CCCCAAGCTTTCAATGATG ATG ATG ATG ATG CAG CTT CCC GGA  
                  GAAG3'  
                  HindIII Stop His His His His His His Leu Lys Gly Ser Phe

The PCR product was digested with *Xho*I and *Hind*III, ligated to pGEX-KG (Guan, K. L., and Dixon, J. E. (1991) *Anal. Biochem.* 192, 262-267) digested with the same restriction enzymes, and transformed into TOP10 *E. coli* cells. After selection of the transformants by restriction enzyme analysis and nucleotide sequencing of the plasmids, a plasmid having the expected size of the insert was found to have also the correct EC2-(His)<sub>6</sub> sequence in frame with the upstream thrombin and GST coding sequence. The plasmid prepared from the selected TOP10 clone was then transformed into BL21 cells. Glycerol batches of selected clones were stored to -80°C.

Figure 9 represents an SDS-PAGE of total proteins of the TOP10 *E. coli* clone which expresses GST-EC2-(His)<sub>6</sub>. This analysis clearly shows that in the extract of the induced sample a protein band with the expected molecular mass (39kDa) was present. The corresponding Far Western Blot clearly shows the E2 specifically reacts with the fusion protein.

#### 6.4 Purification of GST-EC2-(His)<sub>6</sub>

The GST-EC2-(His)<sub>6</sub> fusion protein was purified on a glutathione sepharose column and digested with thrombin (Figure 10). After digestion, the EC2-(His)<sub>6</sub> moiety was further purified by two additional chromatographic steps consisting of a glutathione sepharose column to remove the GST fragment and IMAC chromatography. This procedure is detailed below.

A single colony of an *E. coli* clone expressing the GST-EC2 fusion protein was inoculated in 10 ml LB, 100 µg/ml Amp and cells were grown overnight at 37 °C. The culture was then inoculated in 500 ml of medium and when OD<sub>600</sub> = 0.5 was reached 0.5 mM IPTG was added. After 3.5 hours the cells were harvested by centrifugation, resuspended with 9 ml PBS and disrupted with two passages at 18,000 psi using a French Press (SLM Aminco). The lysate was centrifuged at 30,000xg and the supernatant was loaded on a column of 1 ml of Glutathione Sepharose 4B (Pharmacia) equilibrated in PBS.

The column was washed with 10 ml PBS, and eluted with 4 ml of 50 mM Tris-HCl, 10mM reduced glutathione, pH 8. The eluted proteins were dialysed against PBS and stored to -20°C.

#### 5 6.5 Digestion of GST-EC2-(His)<sub>6</sub> with thrombin and purification of EC2-(His)<sub>6</sub>

9.6 mg of protein recovered from the glutathione sepharose column were digested with 22 units of thrombin (Pharmacia) for 8 hours at room temperature, then the enzyme was inactivated using 0.13 mM PMSF (Sigma). The reaction mixture was then dialysed  
10 against PBS and loaded into 0.5 ml of GST-sepharose column equilibrated in PBS. The column was washed with 1 ml of PBS. The flow-through and the wash were pooled and loaded into 0.250 ml of Nickel-activated chelating sepharose column. EC2-(His)<sub>6</sub> was recovered from the column eluting with 1 ml of 20 mM phosphate buffer, 500 mM NaCl, 400 mM imidazole, pH 7.8. A dialysis was then performed against PBS.

15

#### **Example 7: Binding of CD81 fragment to virus**

The proteins containing the human, but not the mouse EC2 loop of CD81, bound to E2 in western blot (data not shown) and inhibited binding of E2 to human cells (Figure 11).

20

The chimeric proteins were coated on polystyrene beads and incubated with an infectious plasma containing known amounts of viral RNA molecules. After washing, the bead-associated virus was assessed by quantitative RT-PCR for the amount of bound HCV RNA. This experiment was performed as set out below.

25

Polystyrene beads (1/4 inch diameter) (Pierce) were coated overnight with purified EC2 recombinant protein in citrate buffer pH4 at room temperature. After saturation for one hour with 2% BSA in 50mM TrisCl pH 8, 1mM EDTA, 100mM NaCl (TEN) buffer, each bead was incubated at 37°C for 2 hours in 200µl TEN-diluted infectious chimp  
30 plasma containing  $5 \times 10^5$  HCV RNA molecules.

For inhibition experiments, the EC2-coated polystyrene beads were incubated with 10µg/ml of purified monoclonal antibodies for one hour at room temperature before

incubation with the virus. Each bead was washed 5 times with 15ml TEN buffer in an automated washer (Abbot) and viral RNA was extracted using the Viral Extraction Kit (Qiagen). RNA (8 ml) was reverse-transcribed at 42°C for 90 minutes in 20 ml Buffer A (Perkin Elmer Taq Man) containing 100pmol of the HCV antisense primer  
 5 CCGTTCCGCAGACCACTATG, 40 U RNAsin (Promega), 5 nmol dNTPs, 110 nmol MgCl<sub>2</sub>, 10U M-MuRT (Boheringer). cDNA (20 ml) was amplified using a Perkin-Elmer ABI 7700 Sequence Detection System (45 cycles) in 50 ml Buffer A containing 100 pmol of the HCV sense primer TCTTCACGCAGAAAGCGTCTA, 5 pmol of the fluorescent detection probe 5'(FAM)TGAGTGTCTGTCAGCCTCCAGGA(TAMRA)  
 10 (kindly provided by David Slade, Pharmacia and Upjohn), 15 nmol dNTPs, MgCl<sub>2</sub> and 1.25U Taq Gold (Perkin-Elmer, Foster City, CA). All reactions were quantified using HCV (genotype 1a) infected plasma (bDNA titer of 30 mEq/ml) to generate a standard curve. Sequence Detector Software from Perkin-Elmer has been previously described (U. E. Gibson, C. A. Heid and P. M. Williams, *Genome Res.* 6, 995 (1996)).

15

As shown in Figure 12, the molecules containing the human CD81 extracellular loop bound HCV in a concentration-dependent fashion, and pre-incubation of the chimeric proteins with anti-CD81 antibodies inhibited virus binding. Furthermore, serum from chimpanzees which were protected from homologous challenge by vaccination with  
 20 recombinant E1/E2 envelope heterodimer (Q.-L. Choo *et al. Proc. Natl. Acad. Sci. USA* 91, 1294 (1994)) completely inhibited HCV binding to bead-coated-CD81, while serum from vaccinated and non-protected animals did not (data not shown).

These data demonstrate that expression of human CD81, and in particular its major  
 25 extracellular loop are sufficient for binding not only E2 but also HCV particles. Given the wide distribution of CD81 (S. Levy, S. C. Todd and H. T. Maecker, *Annu. Rev. Immunol.* 16, 89 (1998), these results imply that HCV binds and may be internalised by a variety of cells other than hepatocytes. Indeed, HCV RNA has been found in T and B lymphocytes and monocytes (K. Blight, R. R. Lesniewski, J. T. LaBrooy and E. J.  
 30 Gowans, *Hepatology* 20, 553 (1994); P. Bouffard *et al., J. Infect. Dis.* 166, 1276 (1992); Zignego *et al., J. Hepatol.* 15, 382 (1992)). Whether virus binding is followed by entry and infection in all cell types is not clear because of the lack of an efficient HCV culture

system in vitro. It may well be that CD81 is an HCV attachment receptor and that additional factors are required for viral fusion or infectivity.

CD81 participates in different molecular complexes on different cell types, a fact that  
 5 may influence its capacity to serve as a receptor for HCV infection or to deliver  
 regulatory signals to target cells. For instance, it associates with integrins on epithelial  
 and hematopoietic cells (F. Berditchevski, M. Zutter and M. E. Hemler, *Mol. Biol. Cell*  
 7, 193 (1996); B. A. Mannion, F. Berditchevski, S.-K. Kraeft, L. B. Chen and M. E.  
 Hemler, *J. Immunol.* 157, 2039 (1996)), whereas it is part of a signaling complex  
 10 containing CD21, CD19 and Leu13 on B cells (L. E. Bradbury, G. S. Kansas, S. Levy,  
 R. L. Evans and T. F. Tedder, *J. Immunol.* 149, 2841 (1991)). This complex has been  
 shown to facilitate antigen specific stimulation by lowering the activation threshold of B  
 cells (D. T. Fearon and R. H. Carter, *Annu. Rev. Immunol.* 13, 127 (1995)). It is worth  
 noting that HCV appears to use a molecule that is part of the same complex containing  
 15 the EBV receptor (CD21) (N. R. Cooper, M. D. Moore and G. R. Nemerow, *Annu. Rev.*  
*Immunol.* 6, 85 (1988)), and the ability of EBV to activate and immortalise B  
 lymphocytes is well documented.

Together, our data indicate that CD81 is an attachment receptor for HCV and may  
 20 provide new insight into the mechanisms of HCV infection pathogenesis. Since CD81  
 associates with an activation complex on the surface of B cells, the present finding may  
 explain the pathogenesis of HCV associated cryoglobulinemia, even if there is no viral  
 replication in B cells. Moreover, the identification of the interaction between HCV and  
 CD81 may help in mapping conserved neutralising epitopes on the virus envelope  
 25 which should be important to develop effective vaccines and to provide a decoy  
 receptor for viral neutralisation.

Claims

- 1 A CD81 protein, or a functional equivalent thereof for use in the therapy or  
diagnosis of HCV.
- 2 A compound that binds specifically to a CD81 protein, for use in the therapy or  
diagnosis of HCV.
- 3 A method for treating an infection of HCV comprising administering to a  
patient a therapeutically effective amount of a CD81 protein, or a functional  
equivalent thereof or administering a compound that binds specifically to the CD81  
protein, to reduce the infectivity of the virus.
- 4 A pharmaceutical composition comprising a CD81 protein, or a functional  
equivalent thereof, or a compound that binds specifically to a CD81 protein,  
optionally as a pharmaceutically acceptable salt, in combination with a  
pharmaceutically acceptable carrier.
- 5 A pharmaceutical composition comprising a CD81 protein, or a functional  
equivalent thereof, or a compound that binds specifically to a CD81 protein  
optionally as a pharmaceutically acceptable salt, in combination with a  
pharmaceutically acceptable carrier for use in the therapy or diagnosis of HCV.
- 6 A process for preparing a pharmaceutical composition as defined in claim 4, in  
which a CD81 protein, or a functional equivalent thereof, or a compound that binds  
specifically to a CD81 protein is brought into association with a pharmaceutically  
acceptable carrier.
- 7 Use of a CD81 protein, a functional equivalent thereof or a compound that  
binds specifically to a CD81 protein in the manufacture of a medicament for the  
treatment of an HCV infection.
- 8 Use of a CD81 protein, or a functional equivalent thereof in the diagnosis of



## HCV infection

9 An assay for HCV antibodies present in a serum sample comprising the step of  
allowing competitive binding between antibodies in the sample, a known amount of  
5 HCV protein and a known amount of CD81 protein, or a functional equivalent  
thereof and measuring the amount of the known HCV protein that binds to the  
CD81 protein.

10 An assay for HCV in a serum sample comprising the step of allowing  
10 competitive binding between antibodies in the sample and a known amount of CD81  
protein, or a functional equivalent thereof and measuring the amount of the known  
CD81 protein bound.

11 A diagnostic kit comprising a CD81 protein, or a functional equivalent thereof  
15 optionally labeled.

12 A diagnostic kit according to claim 11 wherein the label comprises a  
radioactive label, a peptide, an epitope, an enzyme, or other bioactive compound,

20 13 A method for screening chemical compounds for ability to bind to the region of  
HCV responsible for binding to a host cell, comprising measuring the binding of a  
chemical compound to be screened to a CD81 protein, or a functional equivalent  
thereof.

25 14 A transgenic non-human mammal, carrying a transgene encoding CD81  
protein, or a functional equivalent thereof .

15 A process for producing a transgenic animal comprising the step of introducing  
a DNA encoding CD81 into the embryo of a non-human mammal, preferably a  
30 mouse

16 A nucleic acid molecule which encodes a CD81 protein, or a functional  
equivalent thereof for use in the treatment or diagnosis of HCV.

- 17 A nucleic acid molecule which hybridises to a nucleic acid molecule as defined in claim 16 under standard conditions.
- 5 18 A nucleic acid molecule which hybridises to a nucleic acid molecule as defined in claim 16 under conditions of high stringency (2 x SSC, 65°C).
- 19 The nucleic acid molecule according to any of claims 16-18 which comprises DNA.
- 10 20 A CD81 protein or a functional equivalent thereof for use as a protective immunogen in the control of HCV.
- 15 21 A fusion protein comprising a CD81 protein or functional equivalent thereof for use in the treatment or diagnosis of HCV.

AbstractHepatitis Receptor Protein and DNA

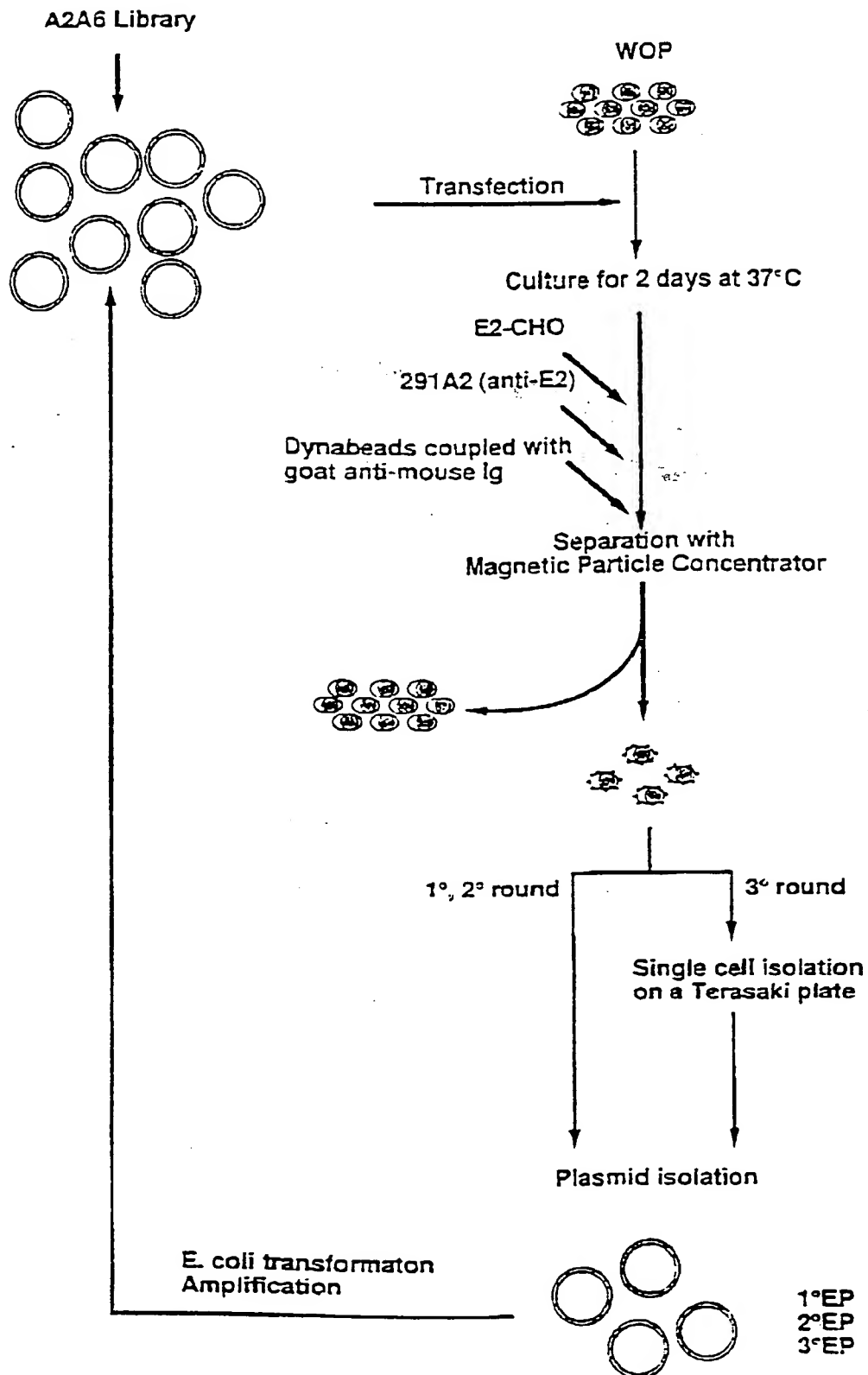
- 5 The use of CD81 protein and polynucleic acid in the therapy and diagnosis of hepatitis C and pharmaceutical compositions, animal models and diagnostic kits for such purposes.

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FIG. 1A

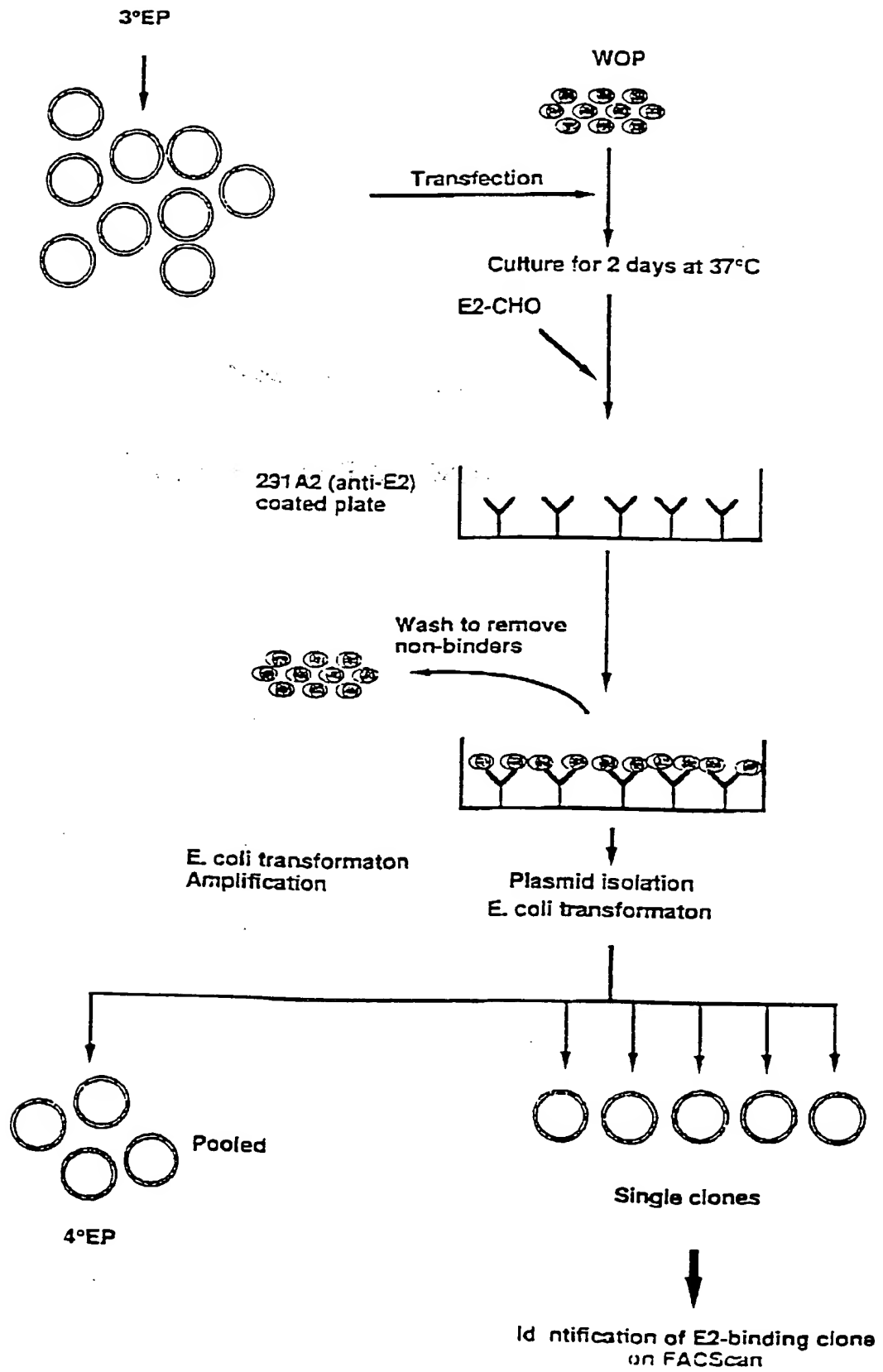
# 1°, 2°, 3° round screening



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FIG. 1B

2/11  
4° round screening



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3/11

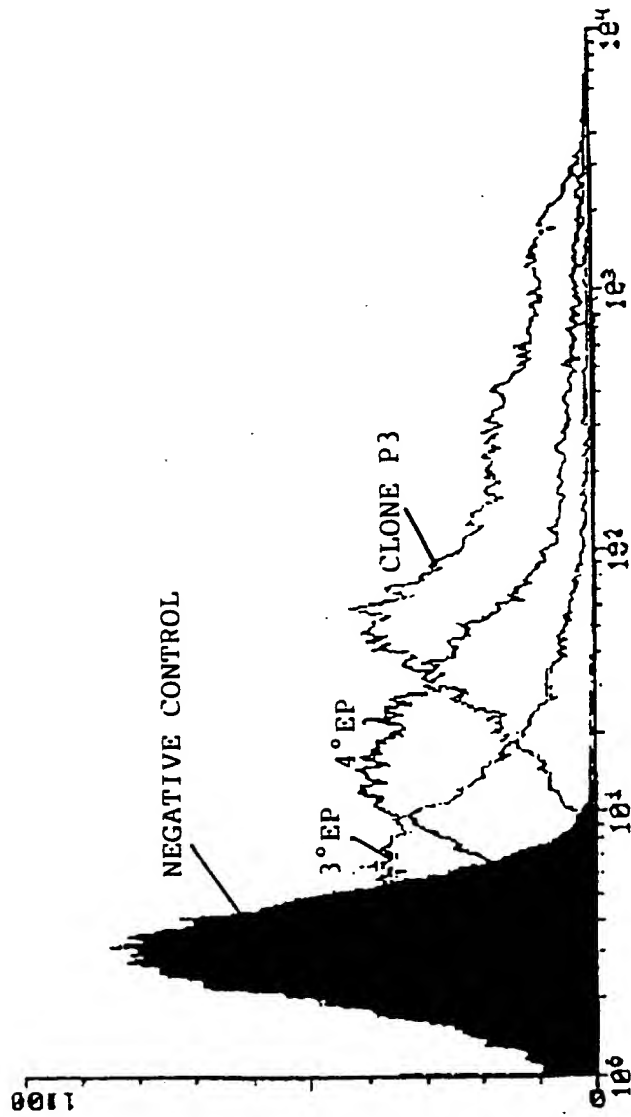
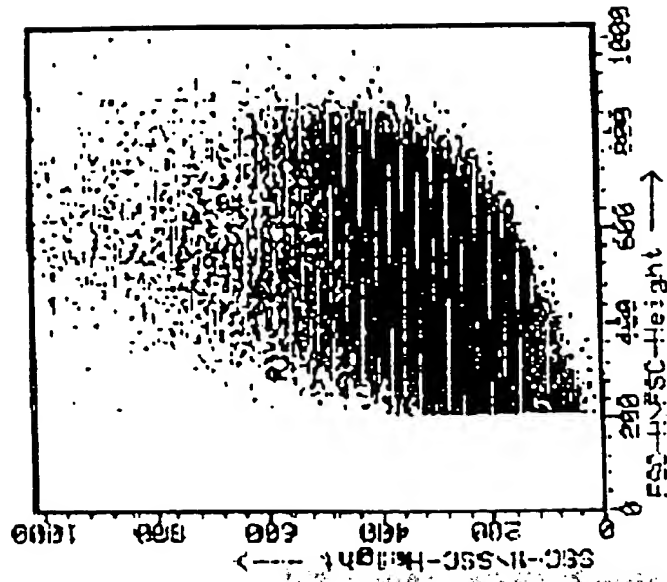


FIG. 2

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FIG. 4

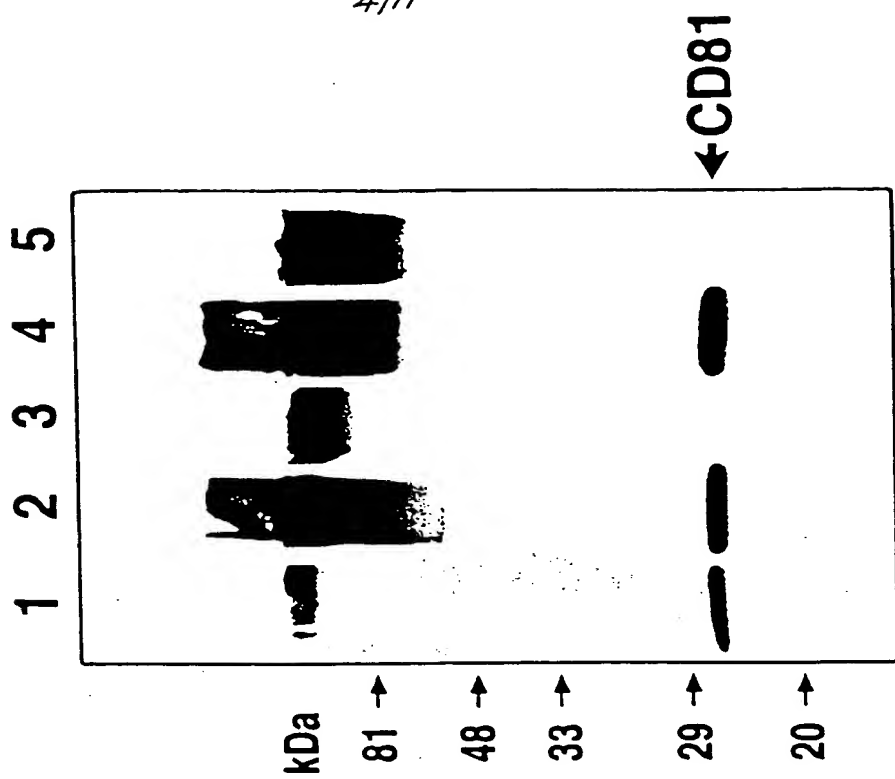
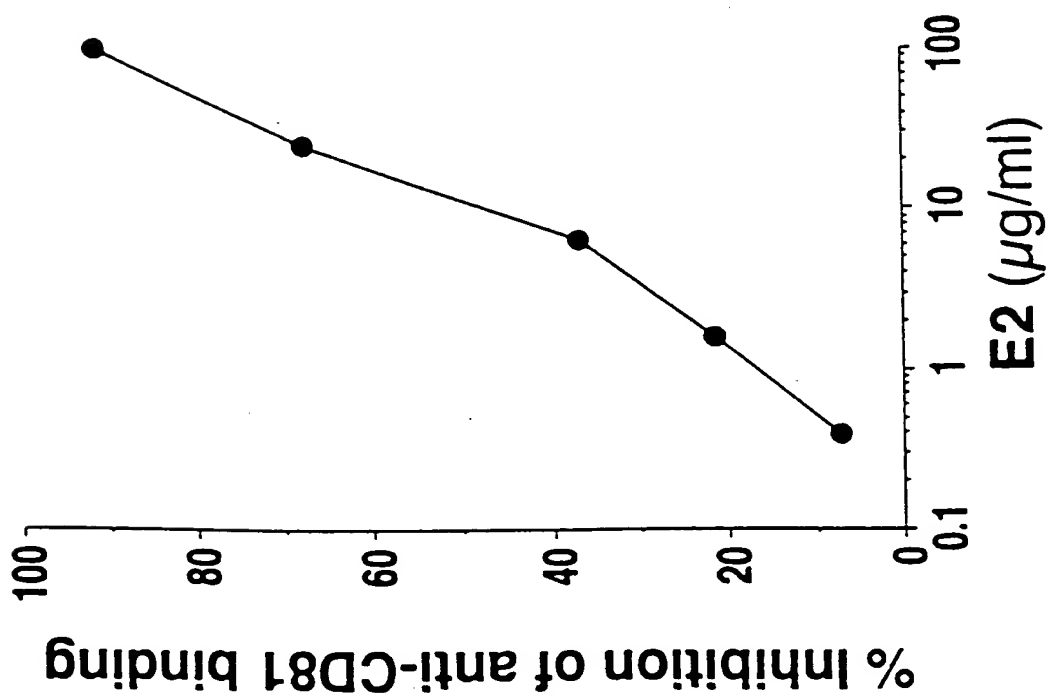
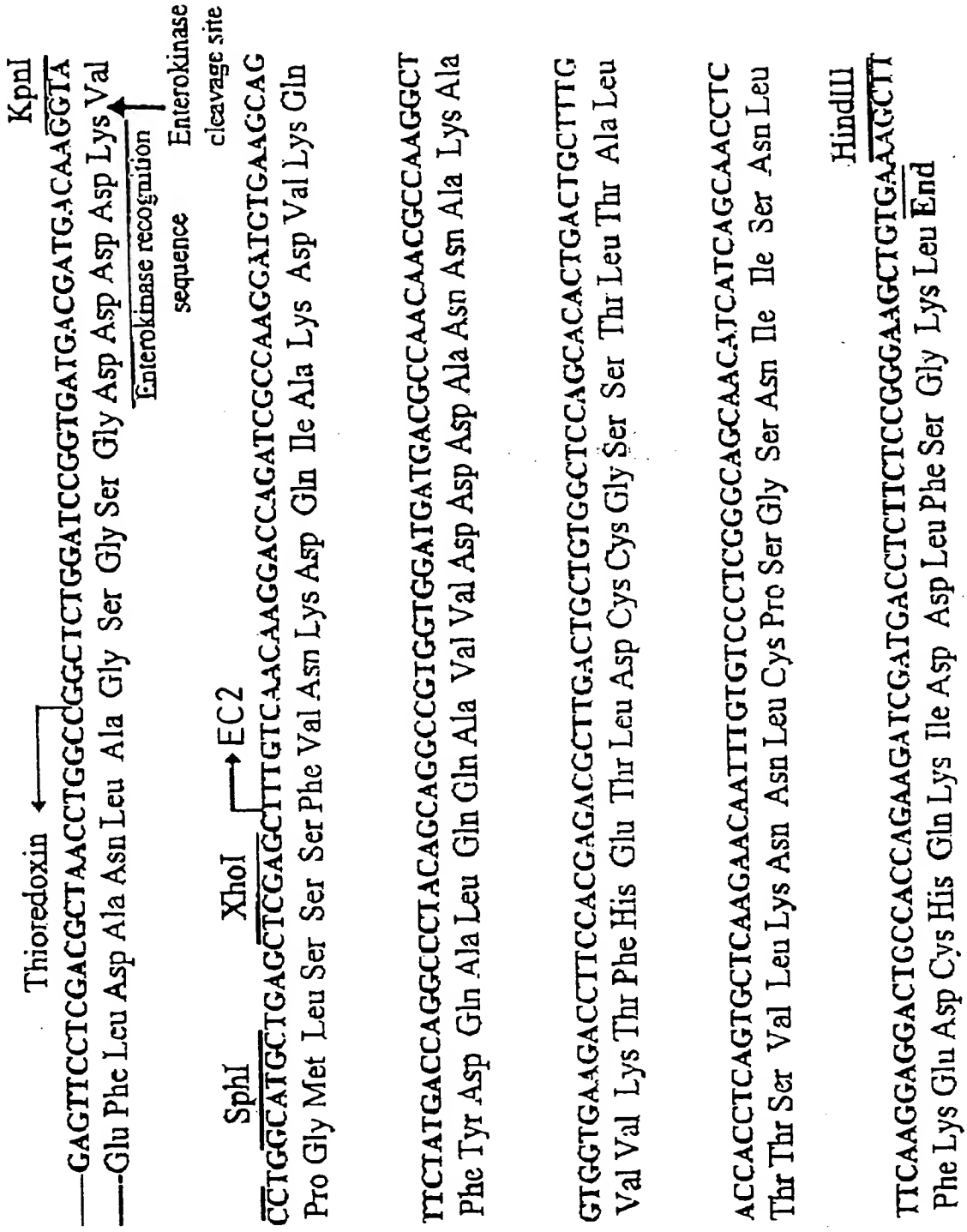


FIG. 3



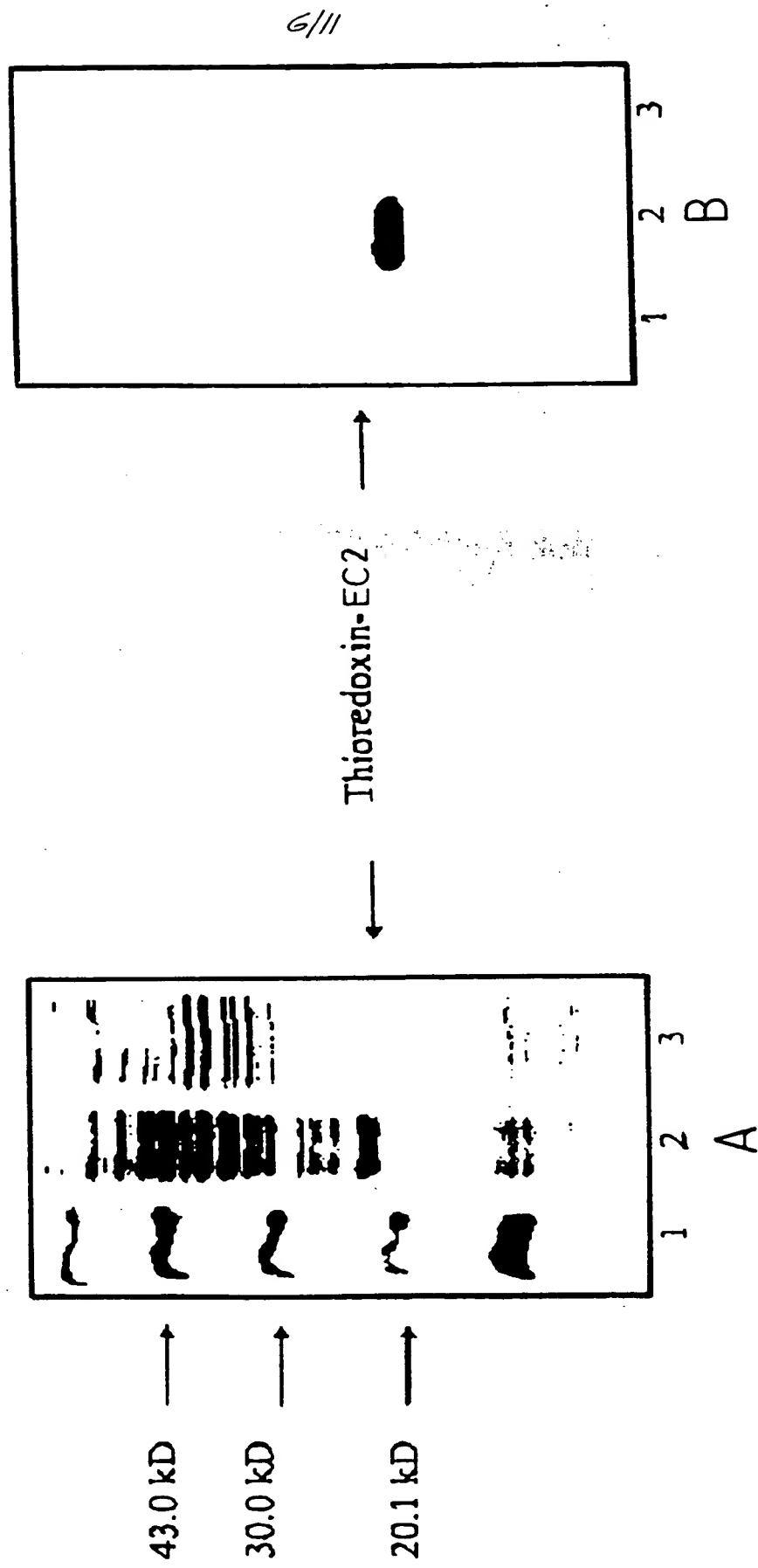
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FIG. 5



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FIG. 6



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FIG. 7

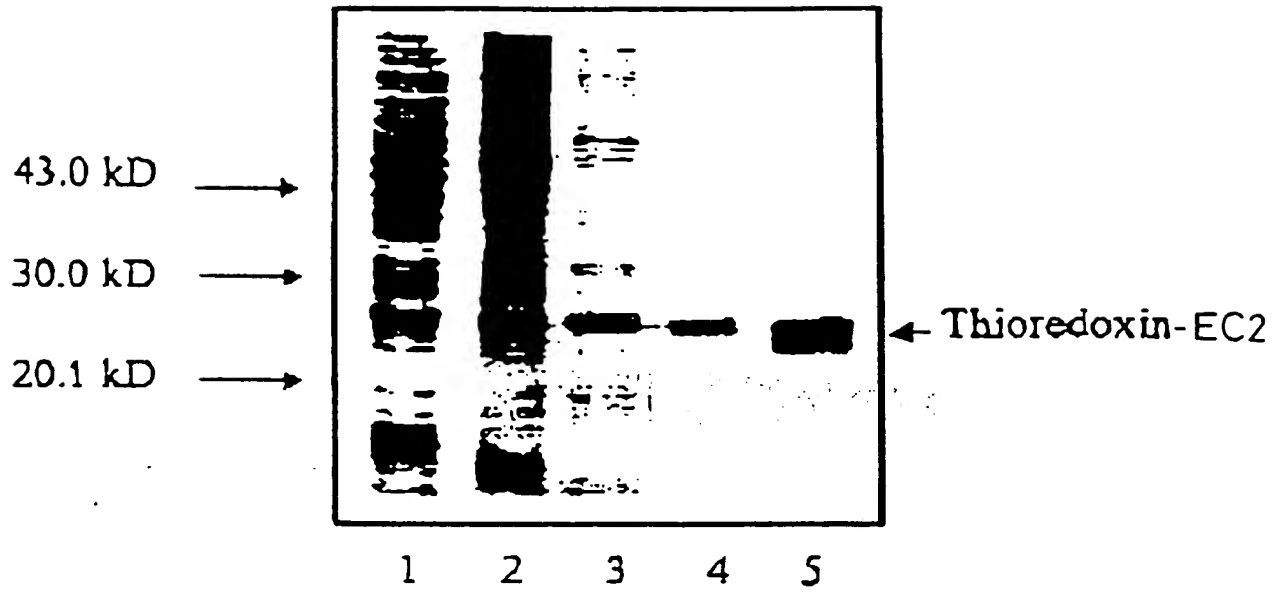
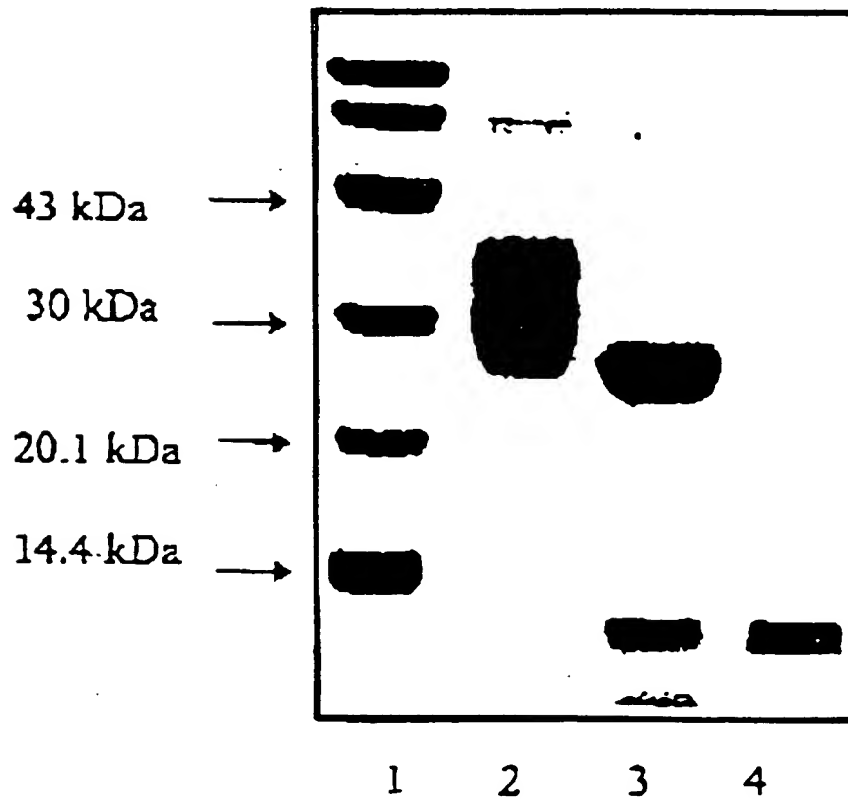


FIG. 10



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FIG . 8

Thrombin cleavage site  
 GST ← CTGGTTCGCGTGGATCCCGGGAATTTC GGIGGTGGTGGTGAATTC TA  
 Leu Val Pro Arg Gly Ser Pro Gly Ile Ser Gly Gly Gly Ile Leu  
 Thrombin recognition sequence

Eco RI

→ EC2  
 TTGTCAACAAGGACCAGATCGCCAAGGATGTGAAGCAG TTCTATGACCAGGCCCTACAG  
 Phe Val Asn Lys Asp Gln Ile Ala Lys Asp Val Lys Gln Phe Tyr Asp Gln Ala Leu Gln

CAGGCCGTGGTGGATGACGCCAACCAAGCGCTGTGGTGAAGACCTTCCACCAG  
 Gln Ala Val Val Asp Asp Ala Asn Ala Lys Ala Val Val Lys Thr Phe His Glu

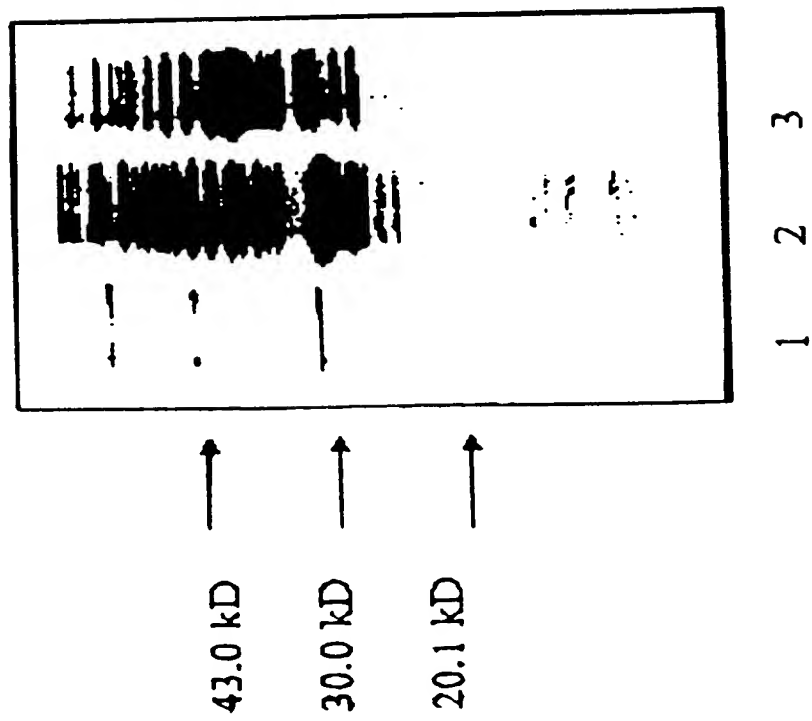
ACGCTTGACTGCTGGCTCCAGCACACTGACTGCTTTGACCACCTCAGTGTCAAGAAC  
 Thr Leu Asp Cys Cys Gly Ser Ser Thr Leu Thr Ala Leu Thr Thr Ser Val Leu Lys Asn

AATTGTGTCCTCGGCAGCAACATCATCAGCAACCTCTTCAAGGAGGACTGCCACCAG  
 Asn Leu Cys Pro Ser Gly Ser Asn Ile Ile Ser Asn Leu Phe Lys Glu Asp Cys His Gln

EC2 ← Hexahistidine tag HindIII  
 AAGATCGATGACCTCTCTCCGGGAAGCTGCATCATCATCATGTGAAGCTT  
 Lys Ile Asp Asp Leu Phe Ser Gly Lys Leu His His His His His End

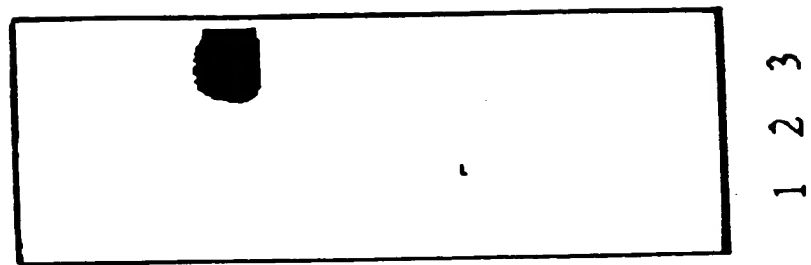
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FIG. 9A



← GST-EC2-(His)<sub>6</sub> →

FIG. 9B

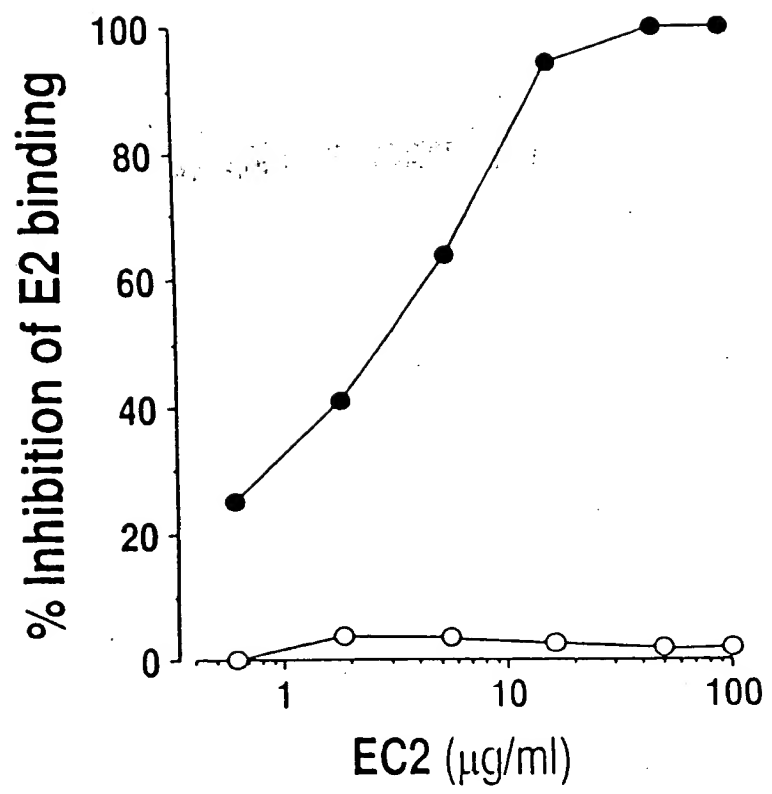


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FIG. II



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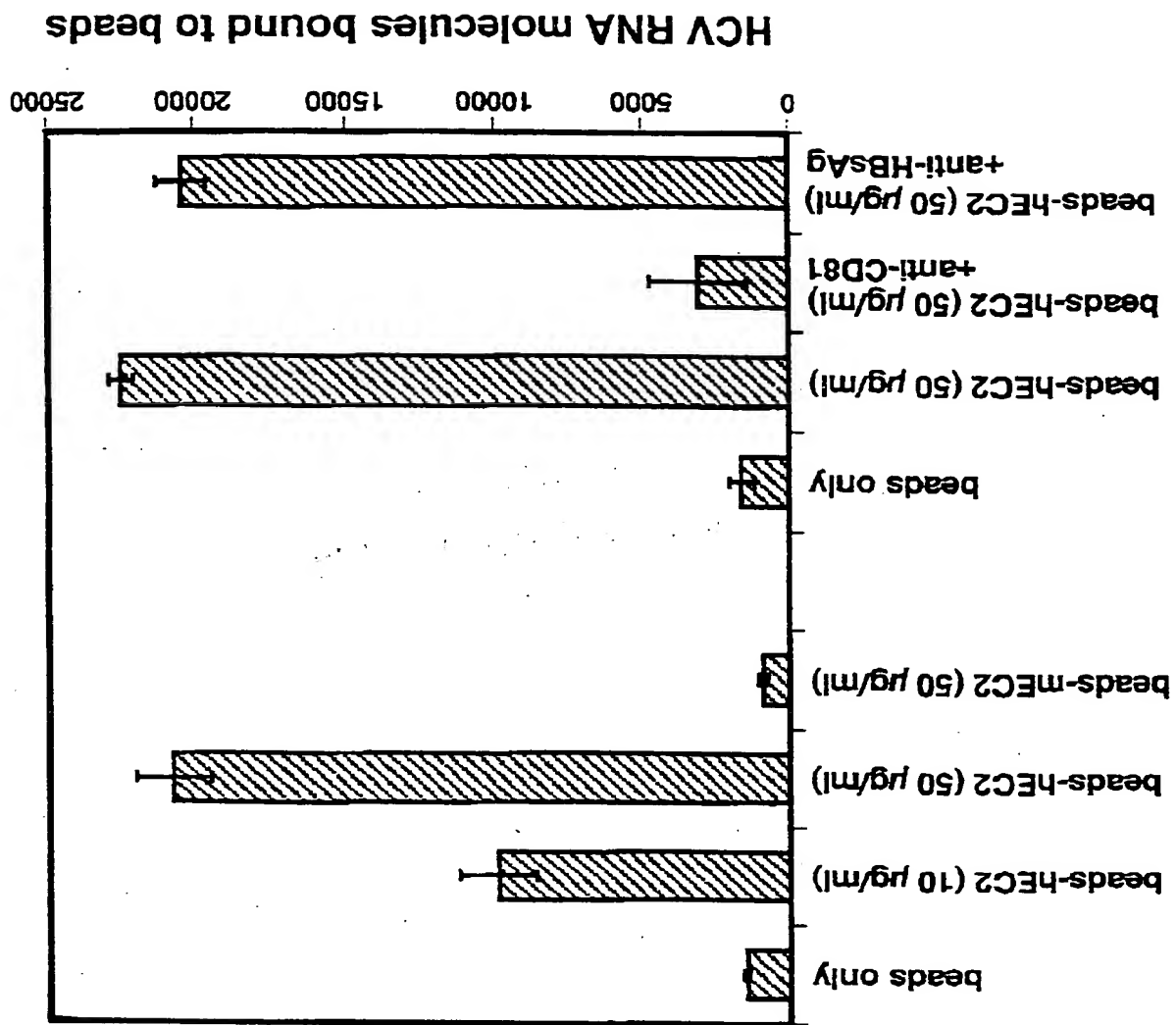


FIG. 12

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